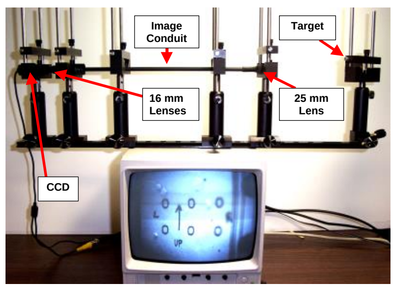
Proposal for a

NSCL-ReA3-FRIB

OPTICS LAB



National Superconducting Cyclotron Laboratory
Revised: July 28, 2015

The NSCL needs a dedicated optics laboratory to:

1. **Develop optical viewing systems for low light and high radiation environments for current CCF operations, ReA3, and FRIB**. This includes the K1200 production target area. A prototype real-time deflector viewing system incorporating flexible Image Conduits and CCD cameras

has been developed that can see light emitted from a Tungsten septum by beam heating at levels as low as 0.020Watts [See Figures 1,2,3 below]. ReA3 and FRIB will require optical systems that can operate in high radiation environments as well.

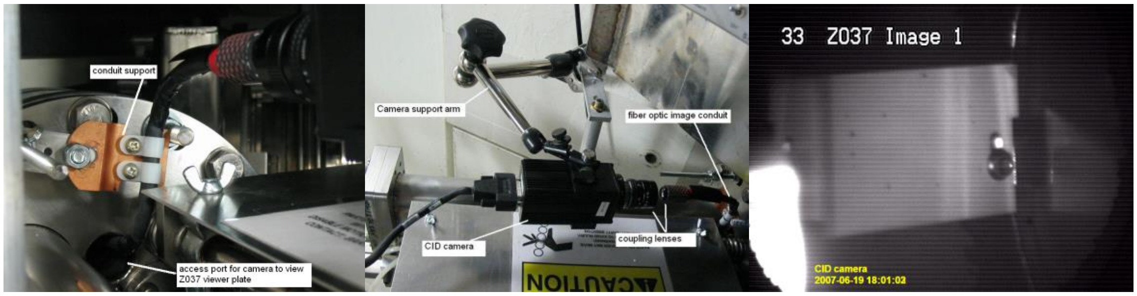


Figure 1: CID camera setup at Z037 using the image conduit. A solid 0.25" diameter image conduit was used here to transmit an image to a CID camera. Use of flexible conduits with GRIN lenses of the same diameter as the fiber will provide an alternative to solid conduits. Both options give us a range of possibilities to view low light phenomena in high radiation environments by allowing the cameras to be placed in low radiation positions thus increasing the lifetimes of the cameras.

Figure 2: Proof of principle test set up of a deflector viewing system capable of monitoring beam induced heating of the septum of the K1200 deflector using a CCD; 'bullet' camera, IR filters to optimize sensitivity to non-visible near-IR blackbody emission at levels *as low as* 0.020 Watts over a 2-5 mm diameter area at the 'notch' of the tungsten septum. This incorporates a single white light LED that can illuminate the entire deflector for remote imaging through a long quartz image conduit to a CCD camera located outside the K1200 vault where it can operate without radiation damage.

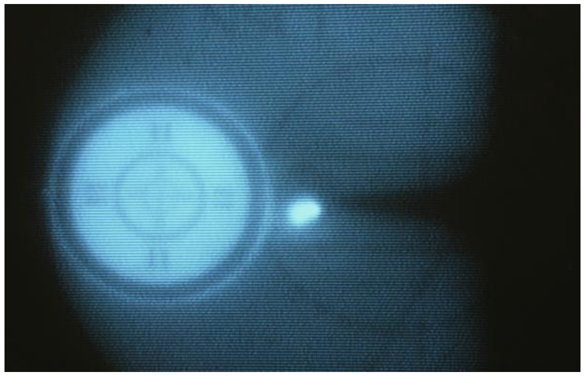


Figure 3: CCD ‘bullet’ camera image of 1:1 scale deflector ‘notch’ at actual operating distances with 0.020 Watt tungsten filament simulating a beam spot. The image is transferred via a small objective lens and a single flexible UHV compatible 0.8 mm diameter 30,000-fiber RADIATION RESISTANT QUARTZ fiber with a length equal to the wall of the cyclotron to transfer optics and the CCD camera with a correct Left/right and up/down image.

2. **Develop Fiber Optic Spectroscopy [FOS] systems for current CCF operations, ReA3, and FRIB** to monitor light emitting processes in sources, critical beamline components, and detection systems. FOS systems will allow us to diagnose, understand and control the physical processes causing the emission of light. These include electrical breakdown events such as arcing, sparking, glow discharges and plasmas. Better diagnostic tools and improved designs will result from this improving reliability and beam delivery. Since the FOS uses Radiation Resistant small quartz single fibers, they can be located next to image conduit systems to correlate visual with spectroscopic information. They can also be engineered into spaces where other detector systems won’t fit. The FOS detector box can also be located away from radiation with the use of long inexpensive fiber optics.
3. **Development of opto-mechanical integrated viewing and spectroscopy systems for current CCF operations, ReA3, and FRIB.** The K1200 Target changer and viewing system is an example of a solution to the costly problem of changing targets. With this system it is possible to replace foils or targets without opening the machine. This system can be used to view targets remotely as well as removing and replacing foils [see figure 3].

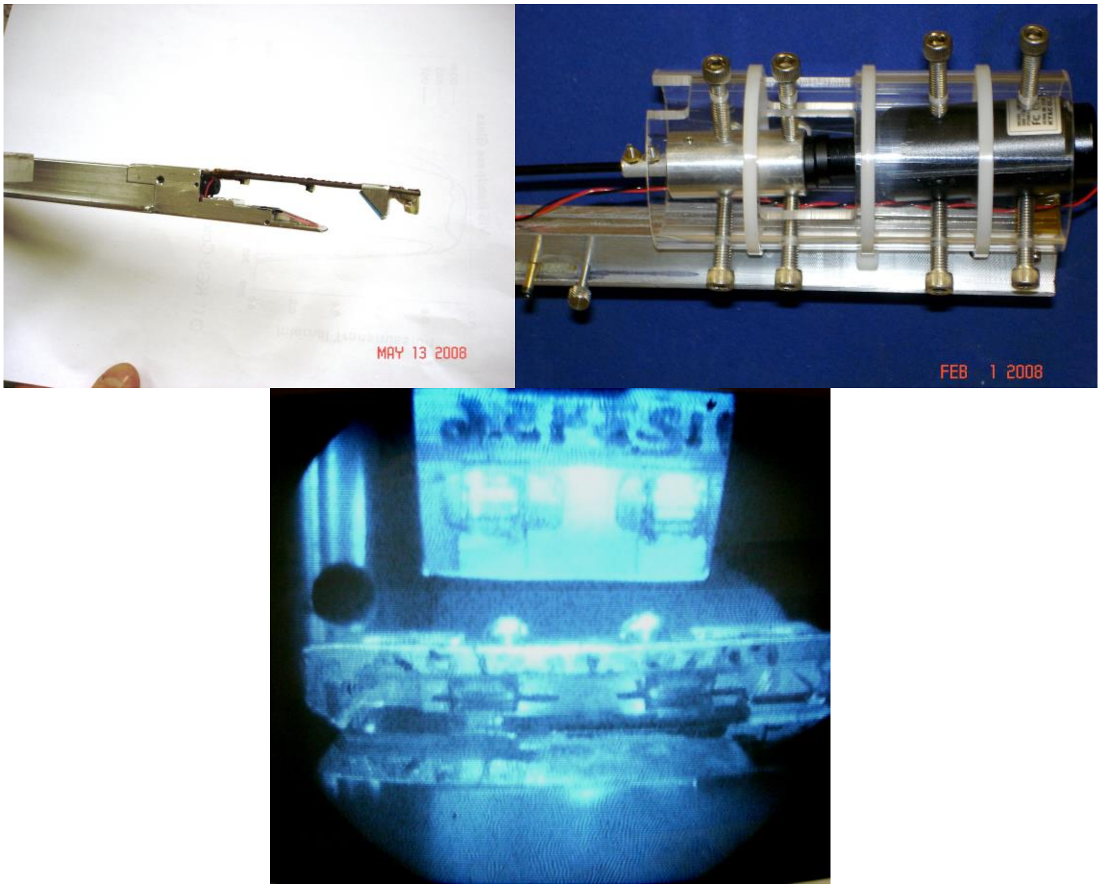


Figure 4: Early prototype K1200 stripper foil changer and CCD optical viewing system is a device for changing targets in the K1200 cyclotron without opening the cap! The current shutdown of the Cyclotron for the reloading of the targets takes about 24 hours to perform and is done currently about every 3 weeks. *Assuming operating costs of about $3000/hour this means a loss of $72000 per target refill. It is possible to radically reduce this down time to about 8 hours [or less] with the Target Viewing System. We can reduce the total shut-down time to 8 hours or a savings of about 16 hours or 16 hrs x $3000/hr = $48000. If the current rate of target replacement every 3 weeks remains the same, then this new procedure could save as much as 17 reloads/year x $48000/reload = $816,000 per year. This will also allow beam delivery to be improved by >3% or 11 days/year. Other optical systems described below can save money by giving us better control over beam delivery.*

Below is a list of some of the other things that a dedicated NSCL-ReA3-FRIB Optics Lab could provide.

1. <u>Optimization of light collection</u> on CCD sensors by matching the lens type and scintillating material. Such studies have led to higher camera sensitivities of secondary beams. For example, by imaging scintillation induced by alphas from Americium-241 on a test bench. Improved optical systems for Beam development and delivery. We have already made great improvements in the viewing systems needed to develop new

beams and deliver them to experimenters. These can be refined further by increased sensitivity of camera systems and higher resolution views of targets and scintillators.

2. Non-destructive testing and debugging camera related hardware under test bench conditions before deploying at camera setups. Mimicking light and focusing conditions on a bench reduces effort and waiting times associated with testing hardware on the field (e.g. in the vaults).
3. Custom optical viewing systems for operations and experimenters. Some of the labs contributions include; the determination of the best method for alignment and viewing of targets, setting up cameras and data acquisition systems, designing and implementing instrumentation for remote operation of sensitive CCD cameras for extreme close up views of targets and scintillators, and the development of an optical systems approach for solving difficult visual observations. A radiation hard glass image Conduit has recently been installed in Image 1. These coherent image conduits give us a vacuum compatible and flexible method for transferring images of targets and viewers from deep inside the cyclotrons or experimental equipment out to appropriate camera and spectroscopic systems. A recent application still in development has shown that the use of a flexible 2-meter coherent image conduit is suitable for monitoring the condition of stripper foils in the K1200 Cyclotron as well as allowing operators to remove and install the foils without opening the cyclotron.
4. Design of remote and multi-element optical systems. Mirrors and lenses in combination with various types of cameras can be used to access hard to reach or high radiation areas.
5. Spectroscopy. Below is the spectra obtained of the Artemis B Argon Plasma identifying exotic Ar^{9+} [Ar X] 553.40 nm optical emission line in Artemis B using a Fiber Optic Spectrometer lines. Plasma Diagnostics: The FOS has recently been used to identify a plasma emission line of Ar X [9+] due to the $2s^2 2p^5$ $^2P_{3/2}$ $^2P_{1/2}$ MI magnetic dipole transition between states of the same parity at 553.4 nm [in the Artemis B source along with more than 25 other lines representing processes at lower plasma energies. The monitoring of plasma spectra in the 190-850 nm range can give important information about plasma conditions such as stability, short and long time scale plasma oscillations, and the identification of unique quantum processes. Future developments could allow 3D imaging of emission zones in the plasma. The temperature of the plasma can also be determined. Spectroscopy can be combined with other optical tools to enhance our understanding of nuclear and associated processes as well as events in plasmas and other light emission processes throughout the lab.

   Inexpensive off-the-shelf and ‘ready for use’ UV-VIS-IR Fiber optic spectrometers have been used to monitor and document chemical and physical processes associated with nuclear or high electric field events in Deflectors in the Deflector Test Stand. They can also be used to determine the composition and thicknesses of thin films. Inexpensive

(about $2000) fiber optic spectrometers can be used to understand electrical breakdown events in SRF cavities, Deflectors, and other detection systems. These Spectrometers will allow us to use the light from UV through visible to near Infrared light (typically 190 to 850 nm) to get spectra with 0.7 nm resolution from light emission events in the millisecond up to more than 60-second time scales. The spectra contain information about the chemical and physical processes involving atoms and ions during sparking, arcing, and glow discharge events. This includes identification the ionization states and determination of temperatures. This research will help us to develop materials that minimize down time due to sparks and subsequent surface damage or coatings on electrodes and insulators [see figure 6].

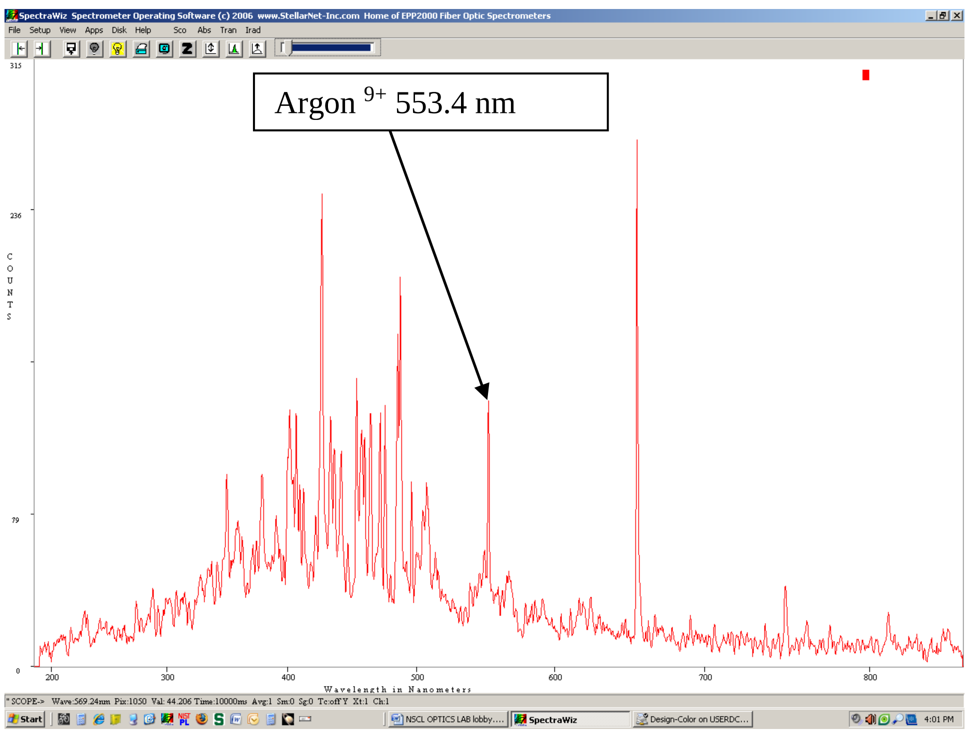


Figure 5: Artemis B Fiber optic spectrometer data showing 20+ identified Argon plasma emission lines including 2 M1 lines due to magnetic dipole transitions. These occur only between states of the same parity. These can be used to measure plasma temperature and as a tool for understanding plasma geometry. The plasma [electron] temperature was calculated using the line intensity ratio method to be about 20,000K +/- 5000K for these specific conditions. The baseline blackbody temperature was found using the best fit through the entire spectra giving an approximate temperature of 6600K. Spectroscopy can be used to identify components and gases involved in breakdown events that impact beam delivery and system reliability.

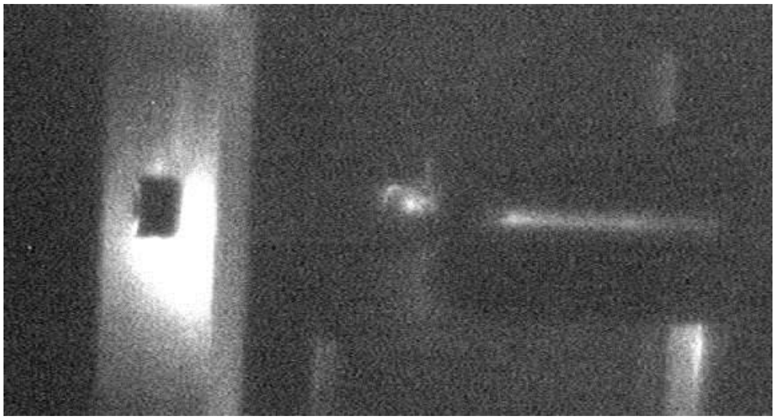


Figure 6: Discovery and documentation of a continuous self-sustaining glow discharge in the deflector test stand. This is the first visually documented case of a glow discharge that breaks down insulators and yet is not detectable by monitoring current and voltage alone during operation. It is also not detectable as a pressure increase in the vacuum since the plasma is self-contained in a small volume of space. This phenomena has been found in many applications around the lab where high voltage and vacuum meet. The damage to components and down time is costly but can be reduced by using imaging and spectroscopic methods for early detection of breakdown events. The plasma in this image dissipated about 0.45 Watts [5 micro amps and 90 kV] which are 'in the noise' as far as operations can monitor - becoming apparent only when the plasma collapses to an arc or spark.

6. Microscopy. Camera systems can be built to view very small targets or objects in real time. They can be used for surface analysis of materials and remote observation of experimental targets or detectors.
7. Metrology. Optical metrology techniques can be used to develop methods of alignment that will be needed for ReA3, FRIB and future experiments with the CCD. Laser alignment, calibration, and guiding of experimental apparatus are also possible.
8. Image guides. We can develop flexible and rigid image guides of various materials to view processes in otherwise inaccessible instrumentation. This can be used in combination with the other systems listed above.
9. Image processing. Image software can process signal using Fourier methods, speckle interferometry, and computer modeling of beam dynamics for many-body studies. Stereo real-time 3D imaging and viewing with special monitors [no special glasses needed] means that sources such as SUSI can be investigated as spatial phenomenon with 3D structure. This is now a real possibility using image conduit and CCD optical systems. Spatial information about plasmas will give valuable information about how they form and how we can optimize and shape plasmas as well as insights into their fundamental physics.
10. Optical Detectors. Now available are second-generation optical detectors and monolithic integrated optics systems that detect light from nuclear processes for high precision cross-section or 3D mapping and stereo

imaging of particle beams. They can be used for beam development and delivery as well and probing the spatial structure of particle ‘packets’.

11. Nuclear Photonics. This is the study of light emitting processes resulting from nuclear interactions with materials. Using a fiber optics spectrometer (item 4 above) we can study real time emission and absorption UV-VIS-IR spectra during nuclear reactions and decay processes. Useful for nuclear and materials science for investigations of primary, secondary and tertiary physical and chemical effects triggered by primary nuclear interactions with targets and detectors.
12. ReA3 and FRIB: We need a network of imaging and spectroscopic systems to monitor beam properties and control of beam dynamics.
13. Cost Savings By providing appropriate optical systems to monitor and control beam delivery the optical solutions already developed or in prototype stages can be used for prevention of damage to critical components such as SRF cavities, sources, beam steering and focusing instrumentation.
14. Remote Viewing and Imaging will also reduce radiation exposure and improve ALARA compliance.

Optics Laboratory Requirements:

1. **Minimum Size: About 30’ by 20’, needs to be large enough to layout 1:1 optical systems with long optical path lengths such as the deflector viewer, target changer and representative spaces such as the chamber of the K1200.**
2. **Needs to be made light tight for tests requiring total darkness.**
3. **Should be capable of storing radioactive components such as cameras.**
4. **Should have an optical bench with associated holders and components.**
5. **Budget for optical workbench, associated instrumentation, computer and tools.**
6. **Key Card Entry**
7. **Storage space/cabinets**

Contributors:

Scott Hitchcock,
Mauricio Portillo,
Tom Beal,
Shannon Krause,
Randy Rencsok